FULL FUEL CYCLE ANALYSES FOR AB1007

Presented at

CEC-ARB Workshop on Developing a State Plan to Increase the Use of Alternative Transportation Fuels

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1. **Introduction**
2. **Methodology**
3. **Example Results**
4. **Summary**

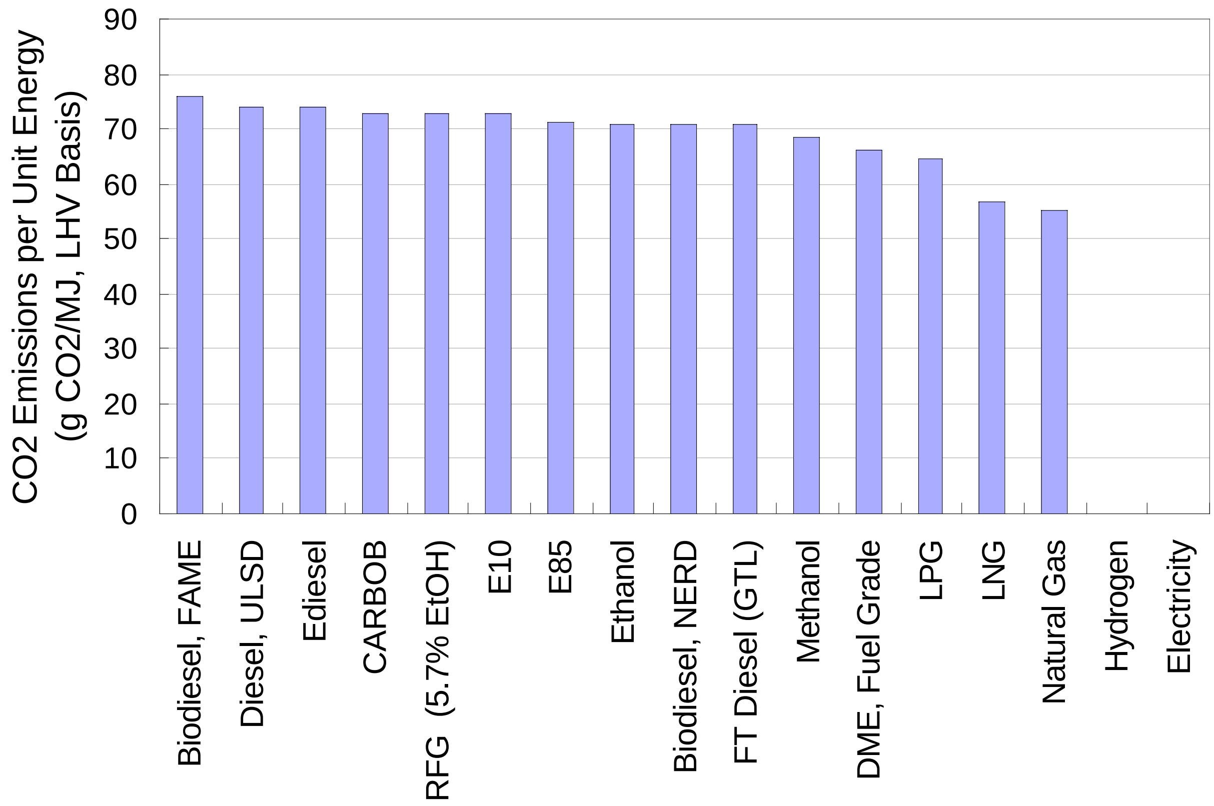
In Assembly Bill 1007 (Pavley) the California Legislature stated:

- The production, marketing, distribution, and use of petroleum fuels causes significant degradation of public health and environmental quality
- Clean alternative fuels have the potential to considerably reduce these impacts and are important strategies to attain air and water quality goals
- Research, development, and commercialization of alternative fuels have the potential to strengthen California's economy by providing job growth and helping to reduce the state’s vulnerability to petroleum price volatility
- CEC and ARB recommended in their report to legislature—“Reducing California's Petroleum Dependency”—that the state adopt a goal of 20 percent nonpetroleum fuel use in 2020 and 30 percent by 2030

AB 1007 requires CEC, in cooperation with ARB and other state agencies, to develop and adopt a state plan to increase the use of alternative transportation fuels

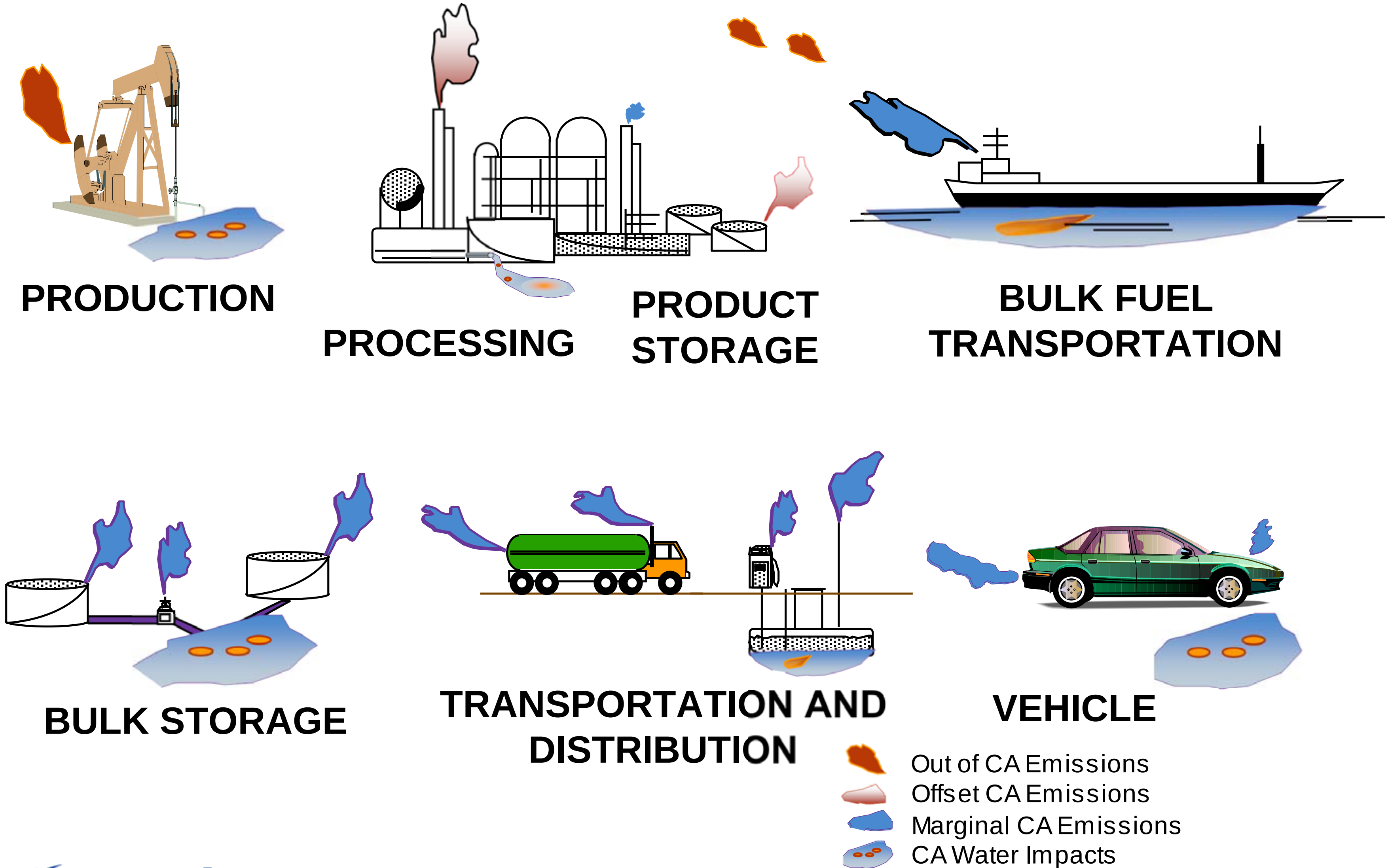
- One component of the plan is a ***full fuel cycle assessment*** of alternative transportation fuels considering emissions of:
  - Criteria air pollutants
  - Air toxics
  - Greenhouse gases
  - Water pollutants
  - Other substances that are known to damage human health
- “Alternative fuel” means a nonpetroleum fuel, including electricity, ethanol, biodiesel, hydrogen, methanol, or natural gas
- The plan shall set goals for 2012, 2017, and 2022

Alternative fuels have lower carbon content in fuel relative to heating value and result in lower CO_2 emissions …



… but we also need to account for WTT and vehicle fuel consumption when comparing CO_2 emissions

Number of emission events throughout fuel cycle



TIAX was tasked with performing the full fuel cycle assessment

- The full fuel cycle assessment (FFCA) analysis was broken down into three parts:
  - The platform for the Well-to-Tank (WTT) analysis is Argonne National Lab's GREET model. The model was adapted to reflect
    - California feedstock and fuel procurement practices including transportation modes, distances, and emission factors
    - Fuel production facility efficiencies and emissions
  - To quantify Tank-to-Wheel emissions, a TTW processor was built incorporating ARB's EMFAC2007 vehicle emission factors with ARB projections of AB1493 compliant vehicle energy consumption ratios
  - The WTT and TTW results are combined in the WTW post-processor, yielding energy and emissions on a per mile basis.
- Analysis years include: 2012, 2017, 2022, and 2030

Draft FFCA Results were published in February 2007 and a joint workshop was held on March 2, 2007.

- Many constructive comments were received and can be summarized as follows:
  - Provide more documentation and more clearly describe each pathway
  - Perform sensitivity analyses on key assumptions
  - Provide WTT results on a neat basis
  - Analyze additional feedstocks/fuels
  - Errors and omissions were identified
  - Additional data was supplied to improve analysis accuracy
- TIAX has been incorporating comments into analysis
- Final reports will be available after the first week of June 2007 incorporating comments received

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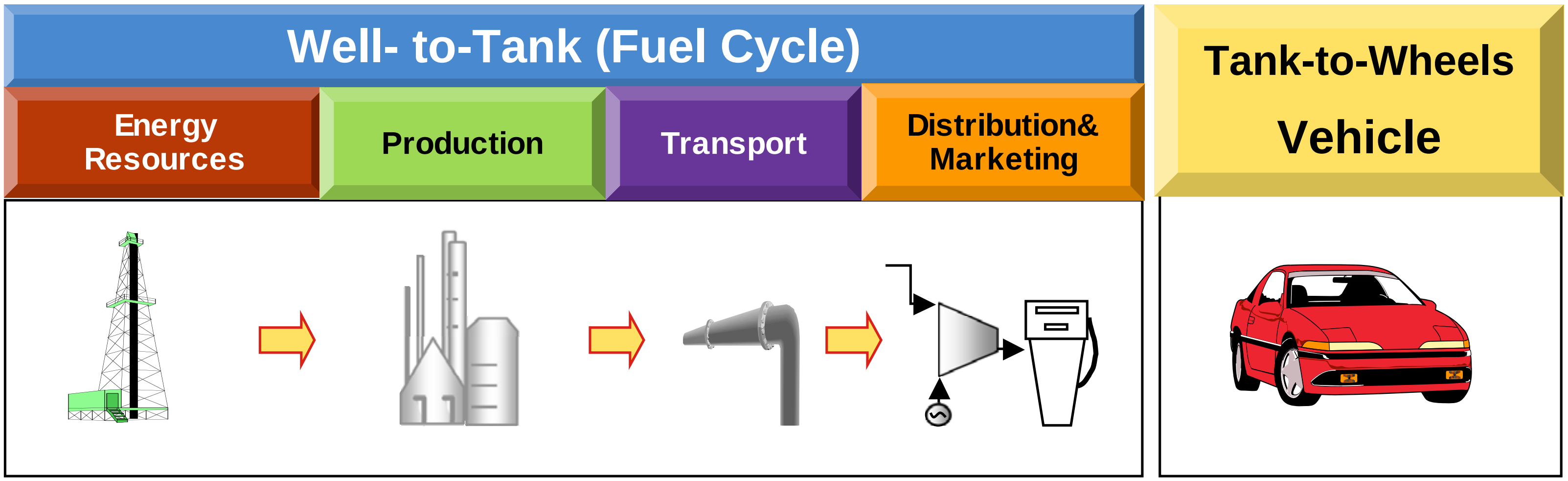
"Well-to-Wheels" Full Fuel Cycle Emission Steps



- Full fuel cycle emissions correspond to resource extraction, fuel production, delivery, and vehicle exhaust, running/evaporative
- Includes combustion, fugitive, and spillage emissions, water discharges
- Emissions from facility and vehicle manufacturing are not included (LCA)
- Energy inputs for fuel cycle are also included

Full fuel cycle analyses provide a basis for determining the energy inputs and emissions from various fuel, feedstock and vehicle combinations

Objectives

- Compare fuel options based on impacts of feedstock extraction, transportation, fuel production and vehicle operation

Fuel Pathways

- Petroleum, natural gas, ethanol, biofuels, synthetic fuels, electricity, hydrogen

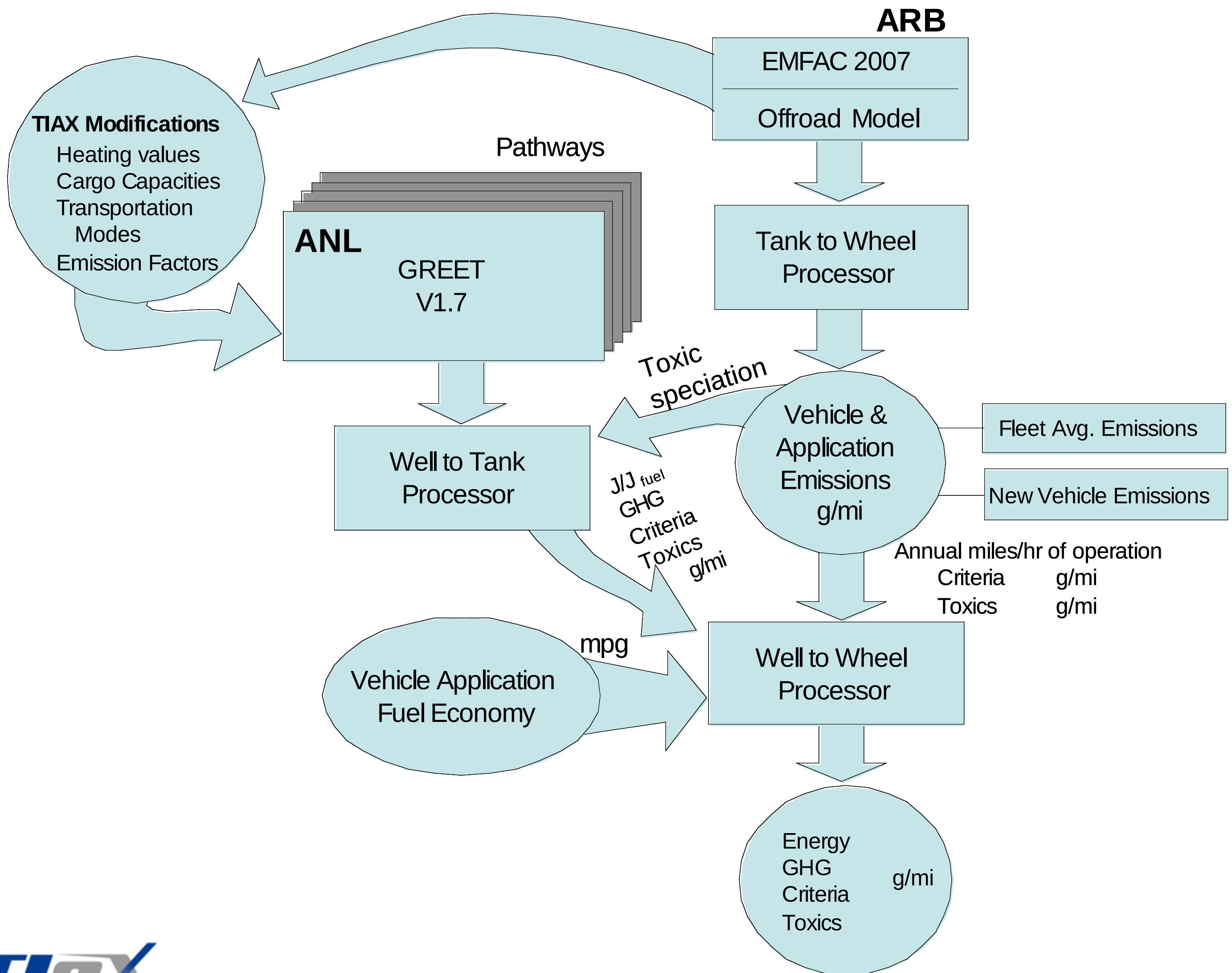
Vehicles

- Light-, medium-, and heavy-duty vehicles, off road vehicles
- Emissions occurring in 2012, 2017, 2022, and 2030
  - New Vehicles (model year 2010 and newer)
  - Existing Vehicles for blends (E10, biodiesel—BD20, FT fuels—FTD30)

Emission Sources and Boundaries

- Criteria pollutants, toxics, and water impacts estimated based on local, state, and Federal standards and rules
- Location of sources: California, North America, and rest of the world
- Global GHG emissions

GREET Used as Backbone of Analysis Methodology for WTT Data



The WTT analysis was based on a modified version of the GREET 1.7 model from ANL

- TIAX modified both baseline inputs and calculations in the model to reflect emission and fuel production scenarios for California.
- Transportation distances reflect the marginal delivery of fuels to California
- Three scenarios reflect fuel production in the U.S., California, and rest of world
- Variety of scenarios for electricity generation including: U.S. average, California average, NG SCCT, NG CCCT and NG CCCT coupled with RPS levels of renewables
- Emission factors for delivery trucks and off road equipment meet California standards
- Emission factors for natural gas transmission equipment in California meet BACT requirements
- Marine and Rail emissions reflect in-port and rail switcher activity with an adjustment factor for urban emissions
- Natural gas transmission and distribution losses reflect data from gas utilities

The WTT analysis was based on a modified version of the GREET 1.7 model from ANL

- Urban emission shares reflect facility and transportation equipment in California
- Model modify to calculate urban emission shares based on the urban distance and total transport distance
- NOx and VOC emissions from combustion equipment at new fuel production facilities require offsets and are therefore set to zero. SO2 emissions from new utility generators are also set to 0 per the Acid Rain Program cap.
- The heating values and carbon contents were adjusted for FTD, reformulated gasoline, and hydrogen.

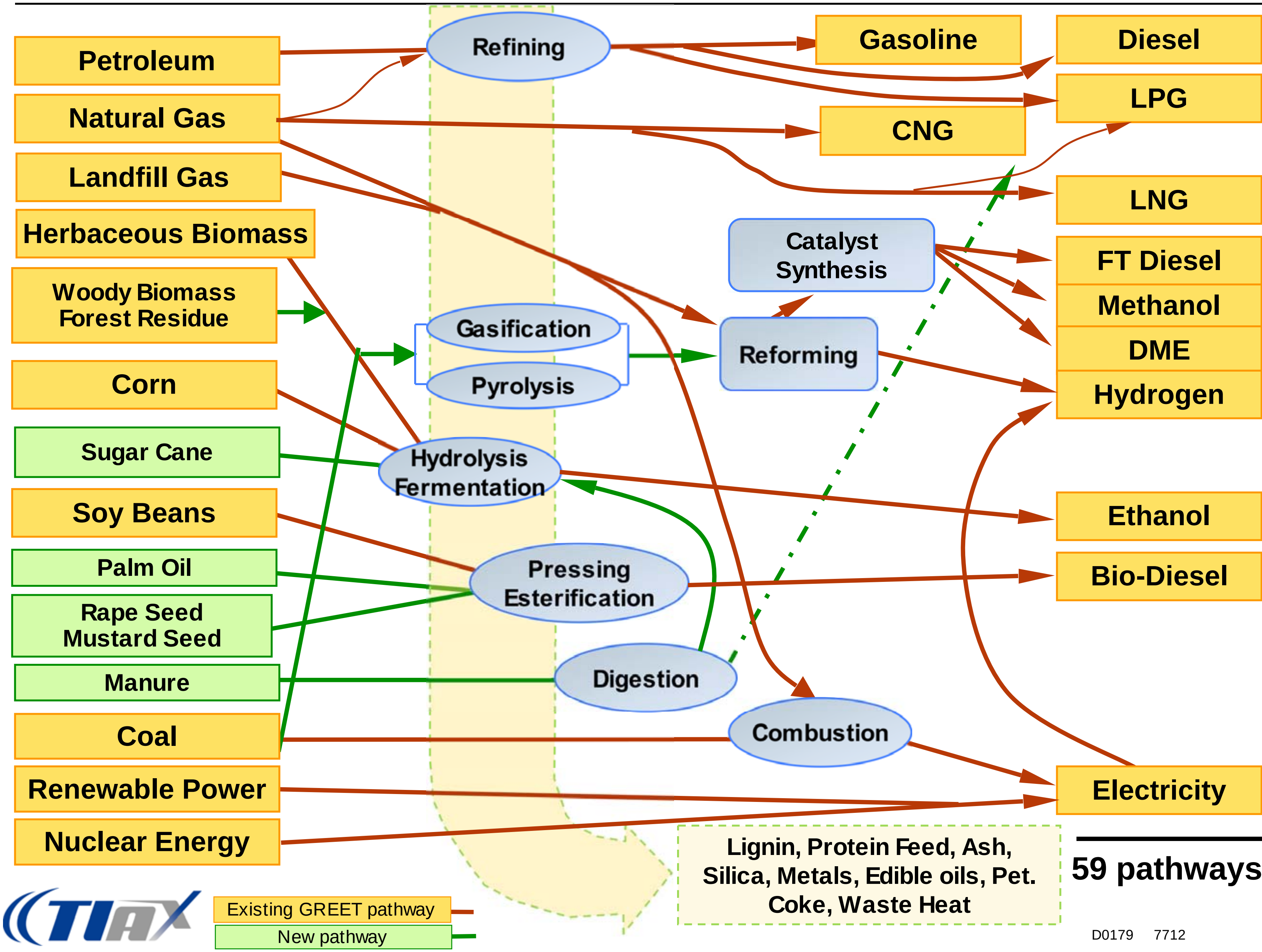
The TTW analysis was based on ARB's Emission Models

- On-road vehicles
  - Criteria pollutant emissions (tpd) and VMT values from EMFAC2007 were used to calculate gm/mi
  - Fuel consumption values for gasoline and diesel vehicles were provided separately by ARB consistent with AB1493, used for energy consumption and CO_2 emissions.
  - For each calendar year (2012, 2017, 2022, 2030) have two analysis options:
    - All model years in fleet (used to evaluate blends)
    - New vehicles: MY2010 and newer
- Off-road equipment emissions based on the recently updated Offroad model

Marginal Analysis Assumptions for Conventional Fuels/Feedstocks

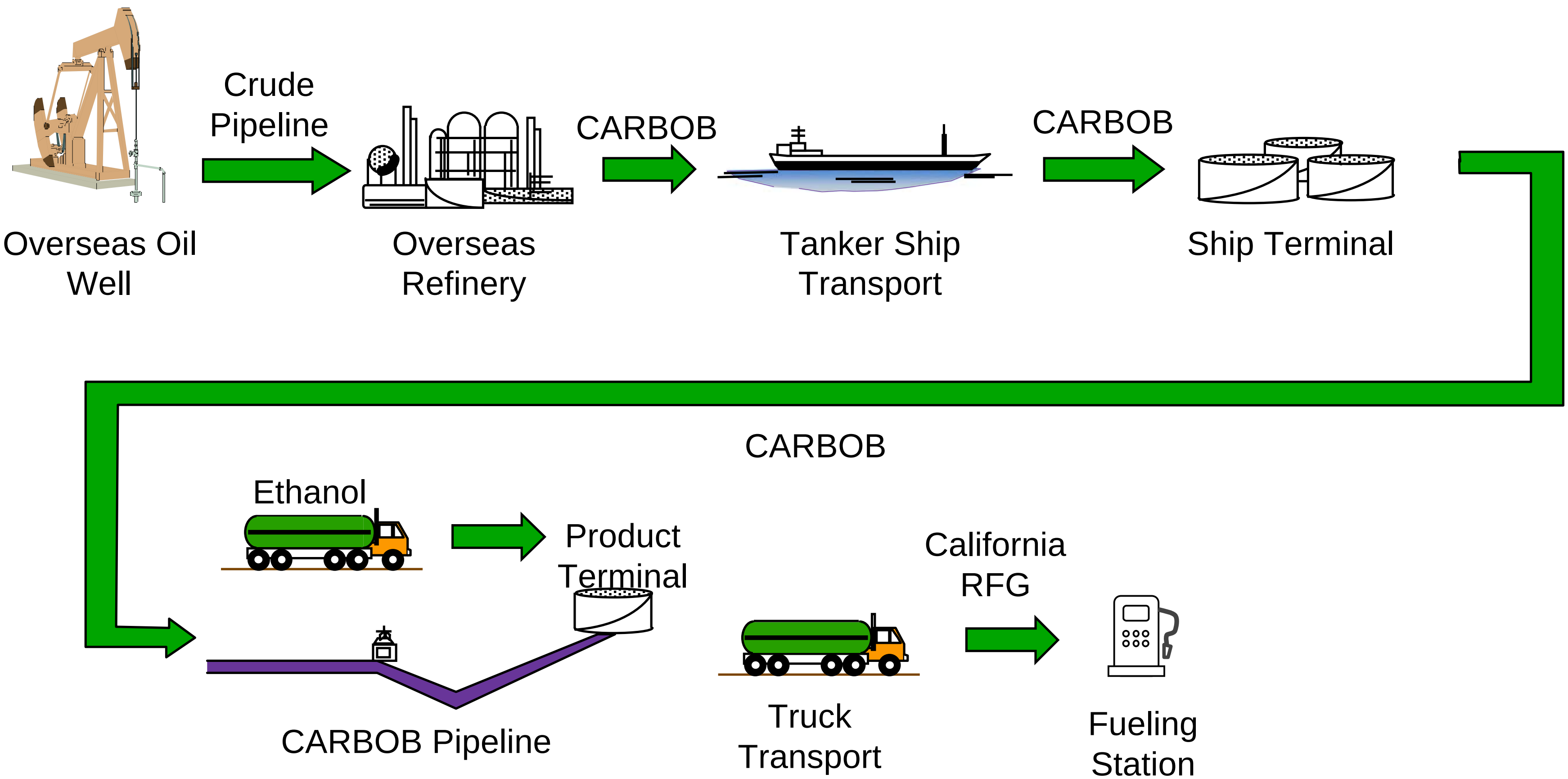
- Gasoline and diesel are imported to California to meet growth in consumption beyond existing refinery capacity
  - Refined products (gasoline and gasoline blend components) imported by ships into California
- Natural gas continued to be shipped to California by pipelines from U.S. and Canada
  - LNG imported by ships
- Electric power generated by natural gas combined cycle plants meeting California's RPS (renewable portfolio standard)
  - No hydro or nuclear considered

Full Fuel Cycle Analyses Methodology *Pathways*

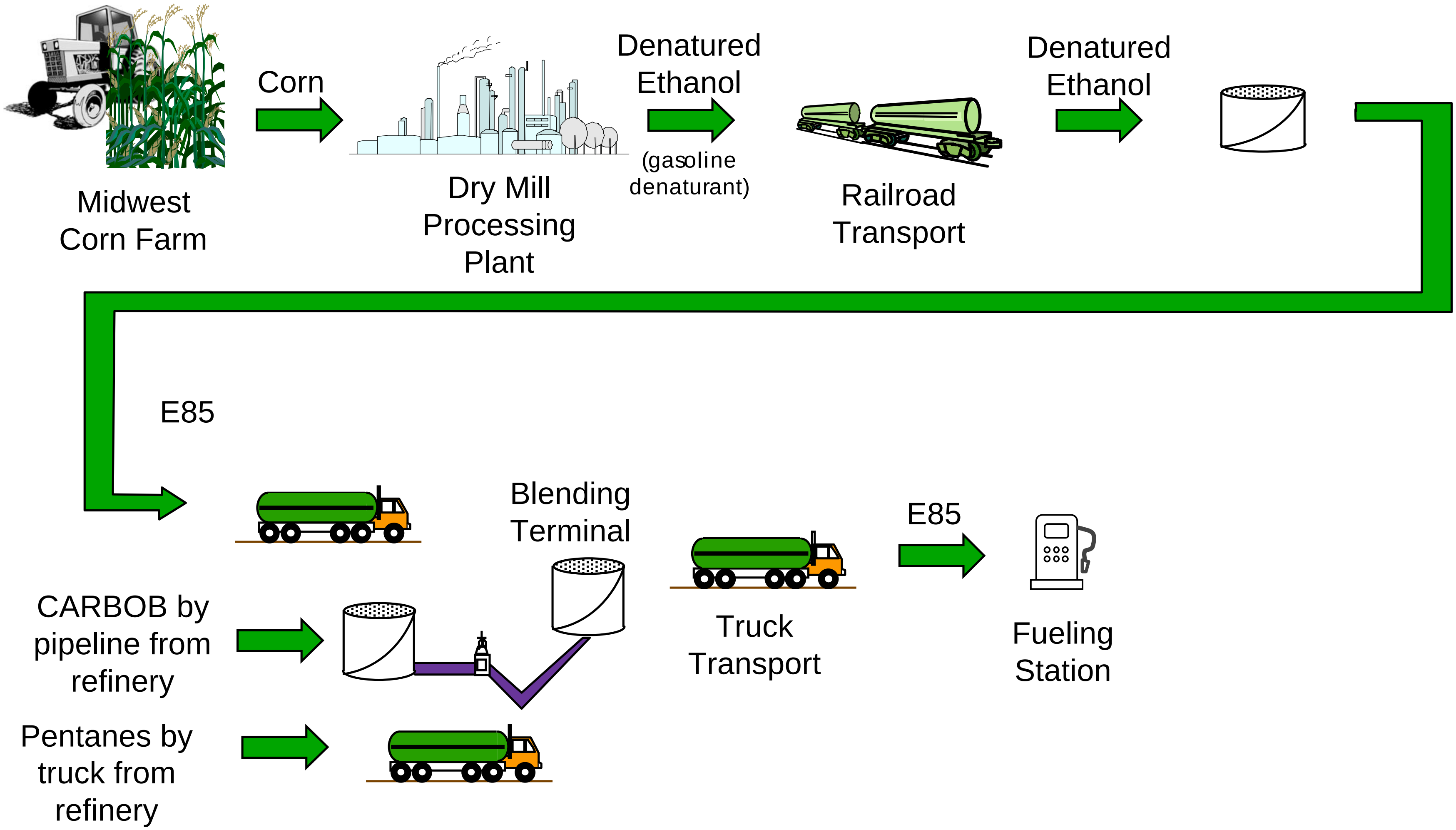


59 pathways

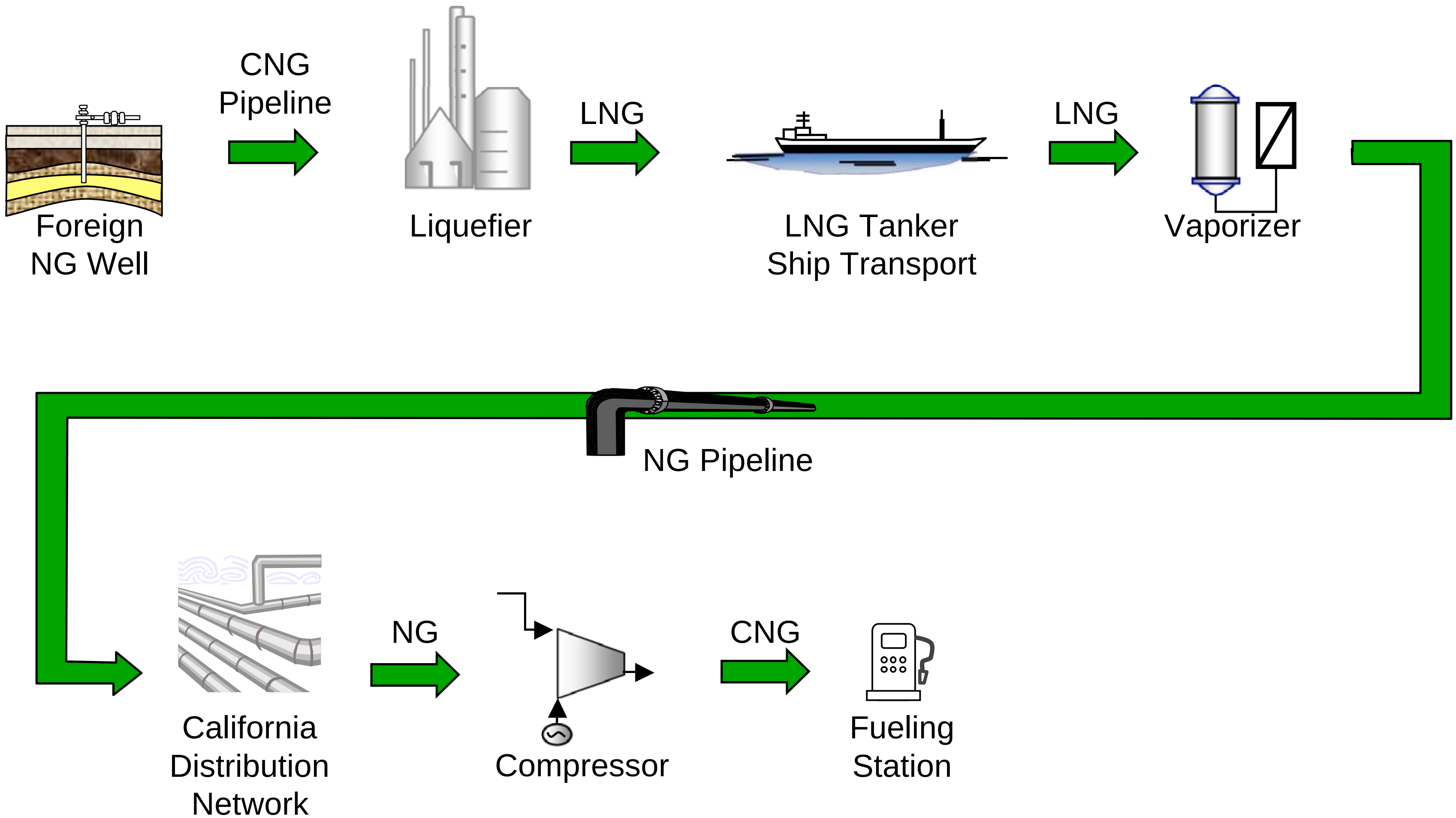
Imported CARBOB from Middle East to California RFG



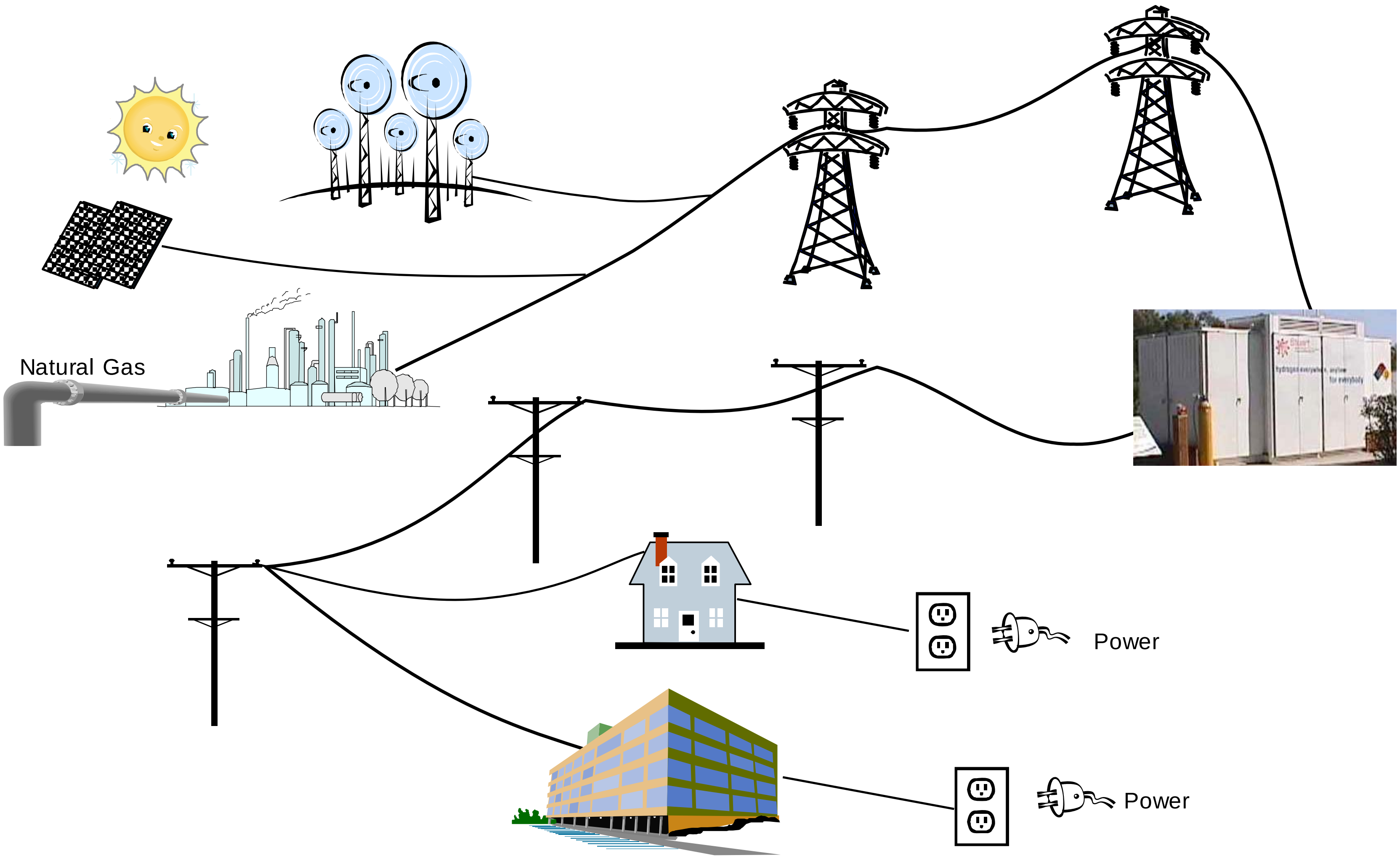
Midwest Corn Based Ethanol Pathway to E85



Imported LNG from Remote Natural Gas to CNG



Marginal Electricity Generation in California



Upward of 59 pathways X 2 vehicle applications X 4 analysis years for criteria pollutants, WTT energy, WTW GHG, toxics, and water pollution

- Six (6) Conventional Fuel Pathways
  - California RFG
  - California ULSD
- Ten (10) Blend Fuel Pathways
  - E10
  - Biodiesel (BD20)
  - FTD (30 percent with Ca ULSD)
  - E-Diesel
- Forty three (43) Neat Fuel Pathways
  - CNG – LNG – LPG
  - Ethanol – Methanol – DME
  - Electricity – Hydrogen

Analysis Years: 2012, 2017, 2022, 2030

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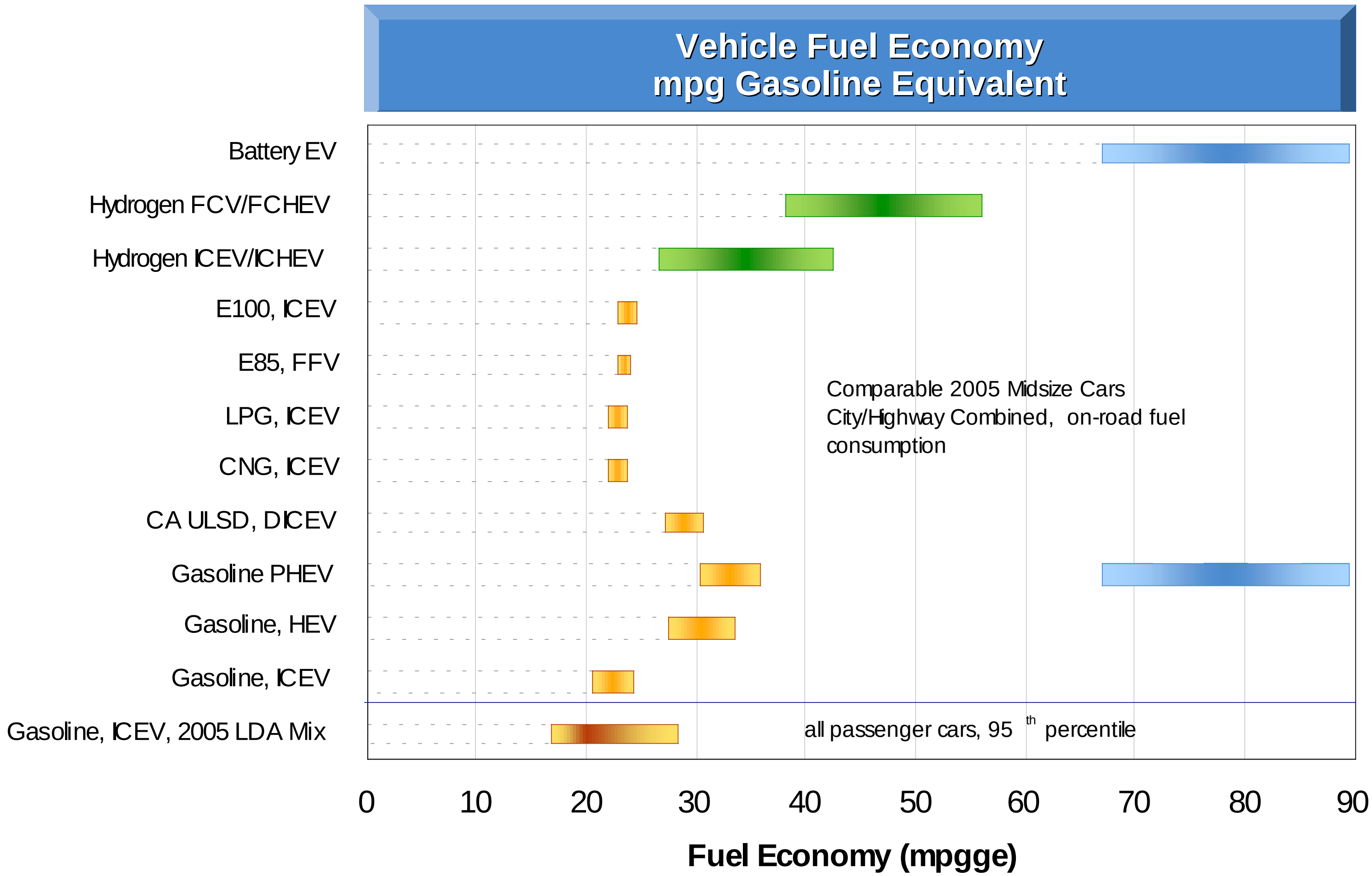
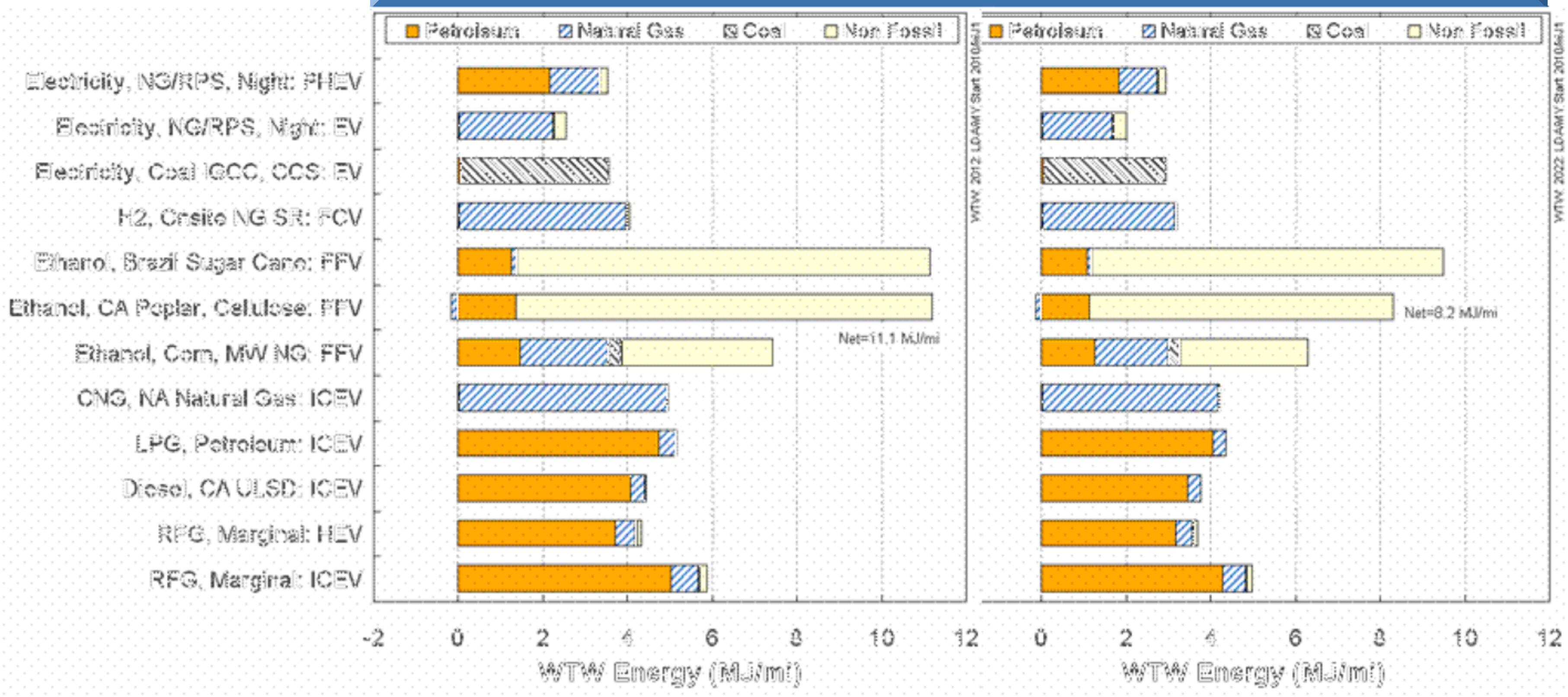
Assumed Midsized Auto Fuel Economy



"Well-to-Wheels" Energy Comparison Midsize Auto

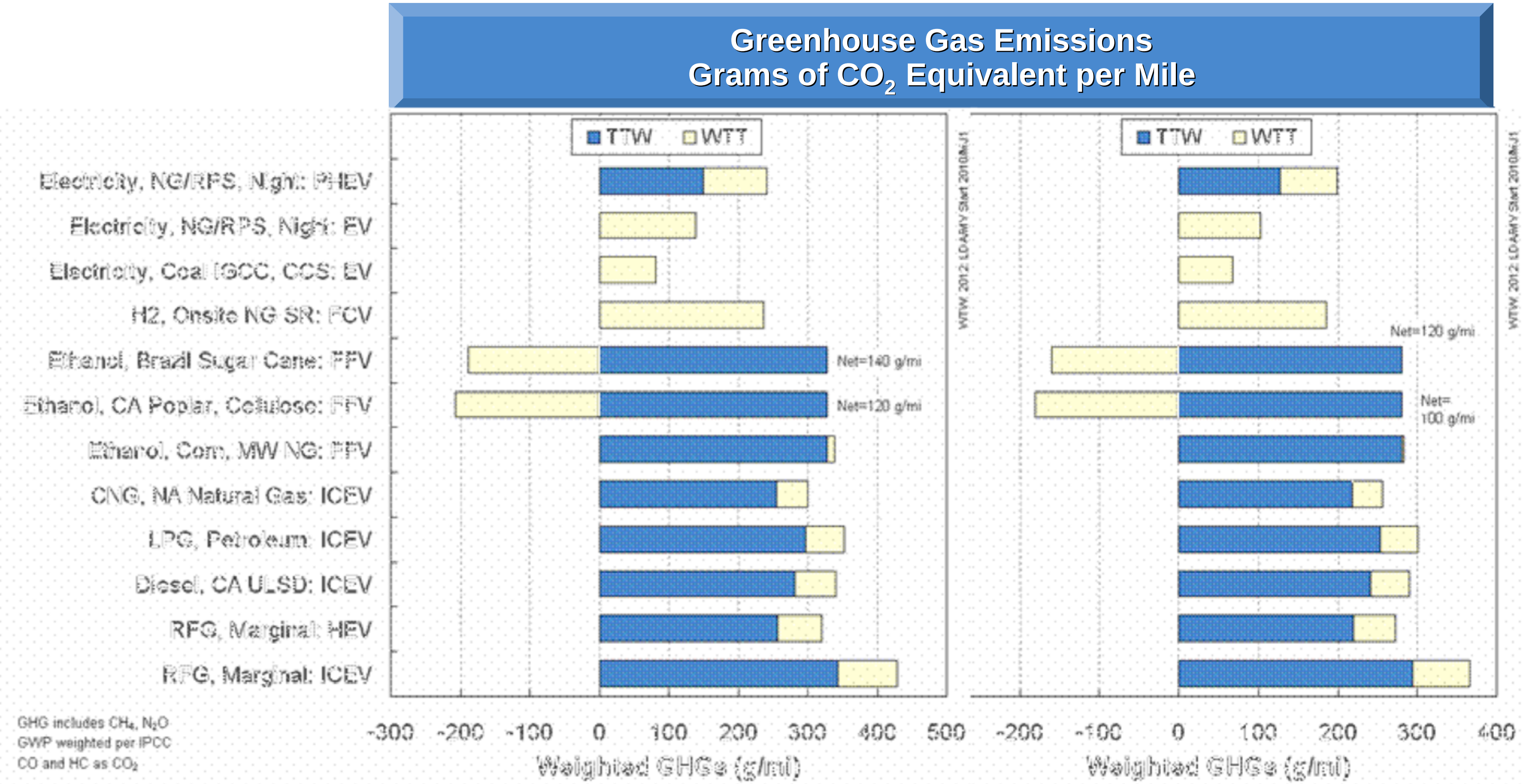
WTW Energy
MJ (LHV) per Mile



Midsize Cars in 2012
MY2010+

Midsize Cars in 2022
MY2010+

"Well-to-Wheels" GHG Emissions Midsize Auto

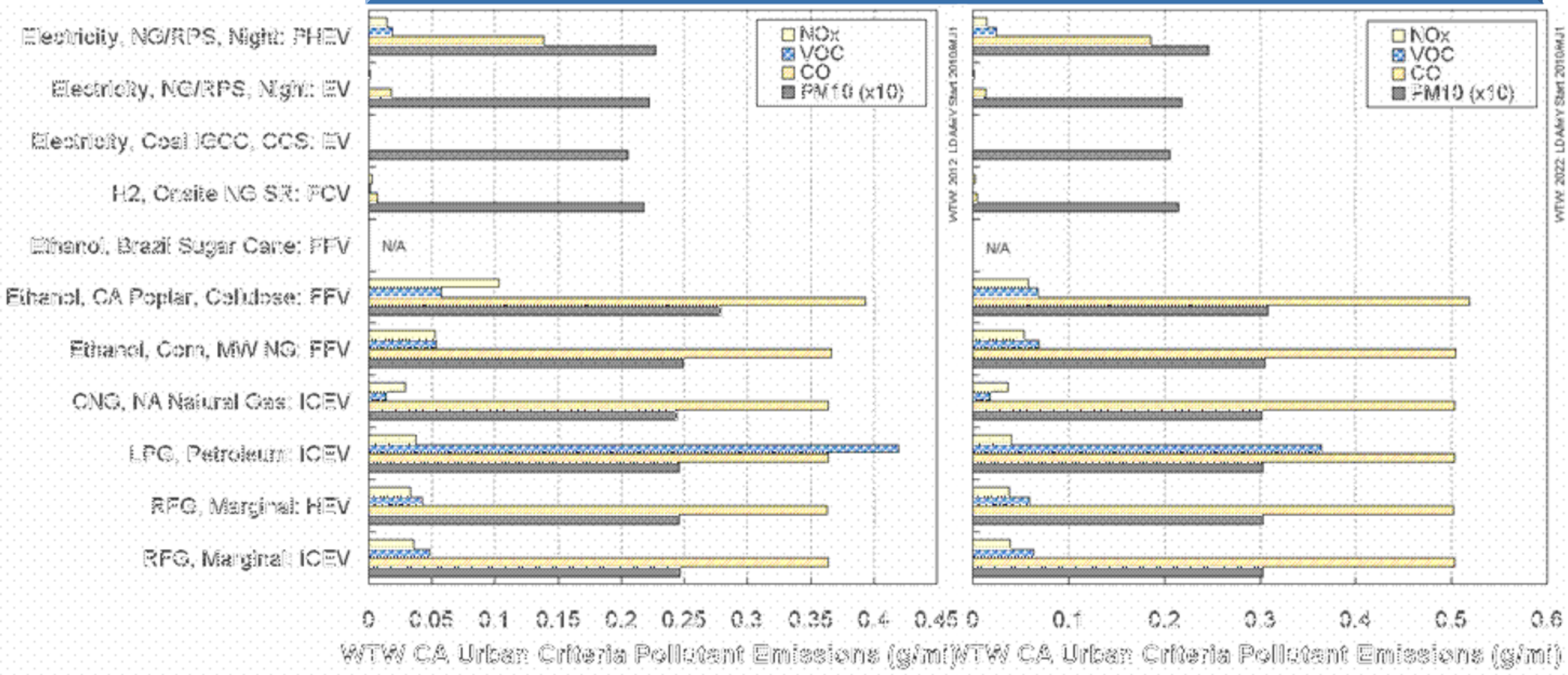


Midsize Cars in 2012
MY 2010+

Midsize Cars in 2022
MY 2010+

"Well-to-Wheels" Criteria Pollutant Emissions Midsize Auto

California Urban Criteria Pollutants Emissions Grams per Mile



Midsize Cars in 2012
MY 2010+

Midsize Cars in 2022
MY 2010+

"Well to Wheels" Observations Midsize Autos

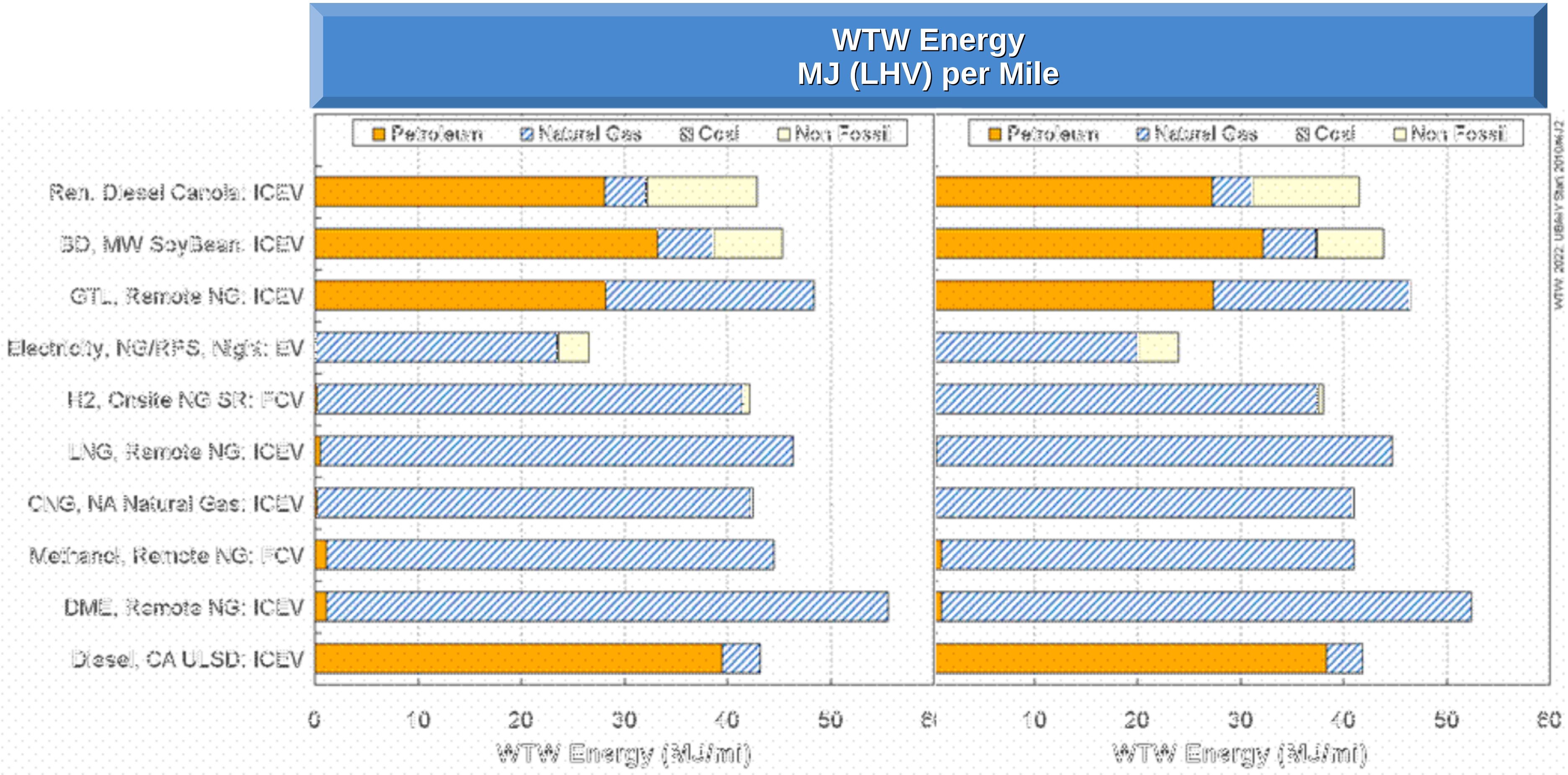
- Primary energy impacts depend on fuel pathway
  - Electricity from renewables or fossil fuels
  - Ethanol from corn, sugar cane, cellulosic biomass
  - Differences largest in GHGs but pathway also affects criteria and toxic emissions
- Using alternative fuels reduces GHG impacts compared to gasoline[1], in most cases improving over time

Fuel	GHG Benefit	Fuel	GHG Benefit	Fuel	GHG Benefit
Corn Ethanol	0 to 30%	Diesel	20 to 22%	PHEV	42 to 48%
Cellulosic Ethanol	70 to 80%	LPG	18 to 23%	Battery EV	70 to 85%
CNG	30%	Gasoline HEV	25%	Onsite NG reformed H2	40 to 50%

- Alternative fuel pathways result in criteria emissions comparable to gasoline
  - LPG VOCs higher if not controlled
  - California biomass based fuels increases PM and NOx emissions slightly, decreasing over time
  - Natural gas based hydrogen and electric pathways reduce criteria pollutants
- Air toxics dominated by diesel exhaust PM

"1. Results for fossil fuel based pathways (except for cellulosic ethanol). Renewable pathways result in lower GHG emissions.

"Well-to-Wheels" Energy Comparison Urban Buses

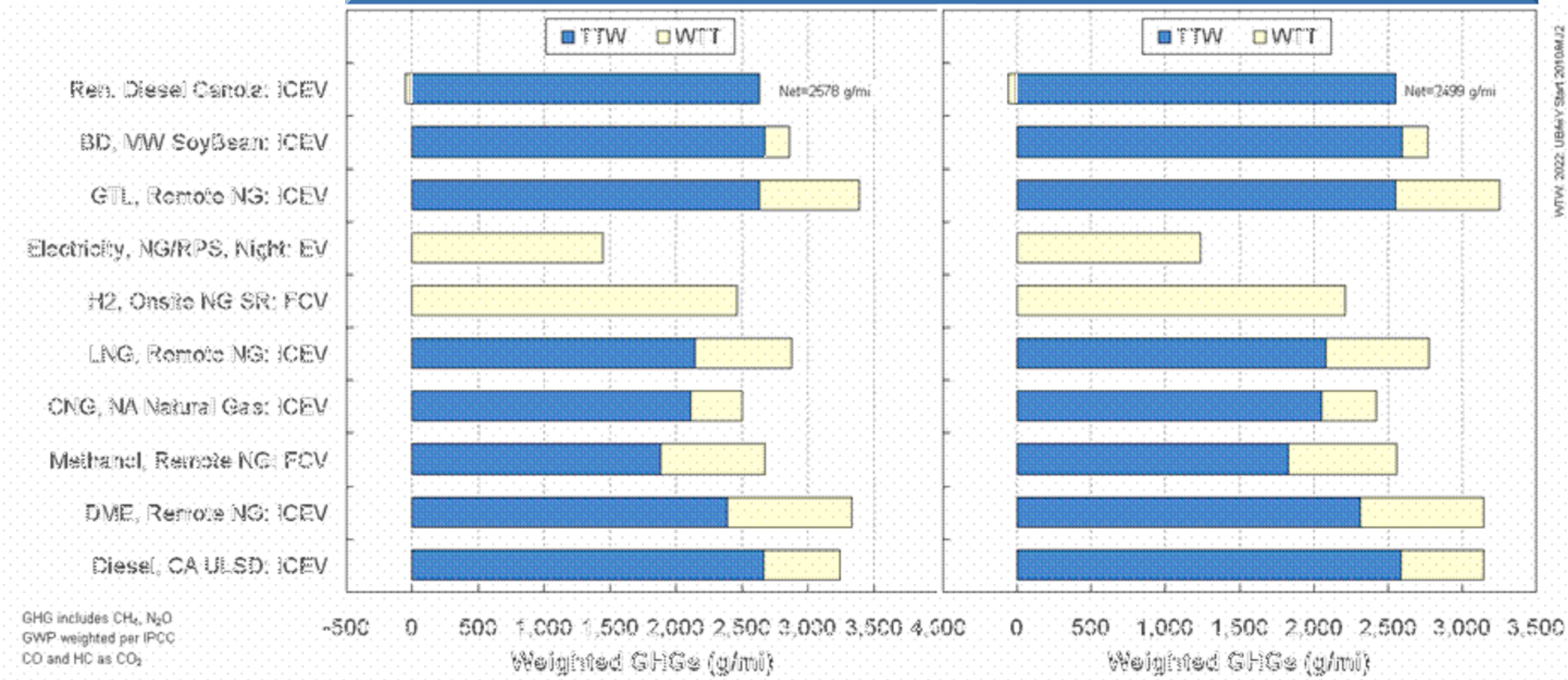


Urban Buses in 2012
MY2010+

Urban Buses in 2022
MY2010+

"Well-to-Wheels" GHG Emissions Urban Buses

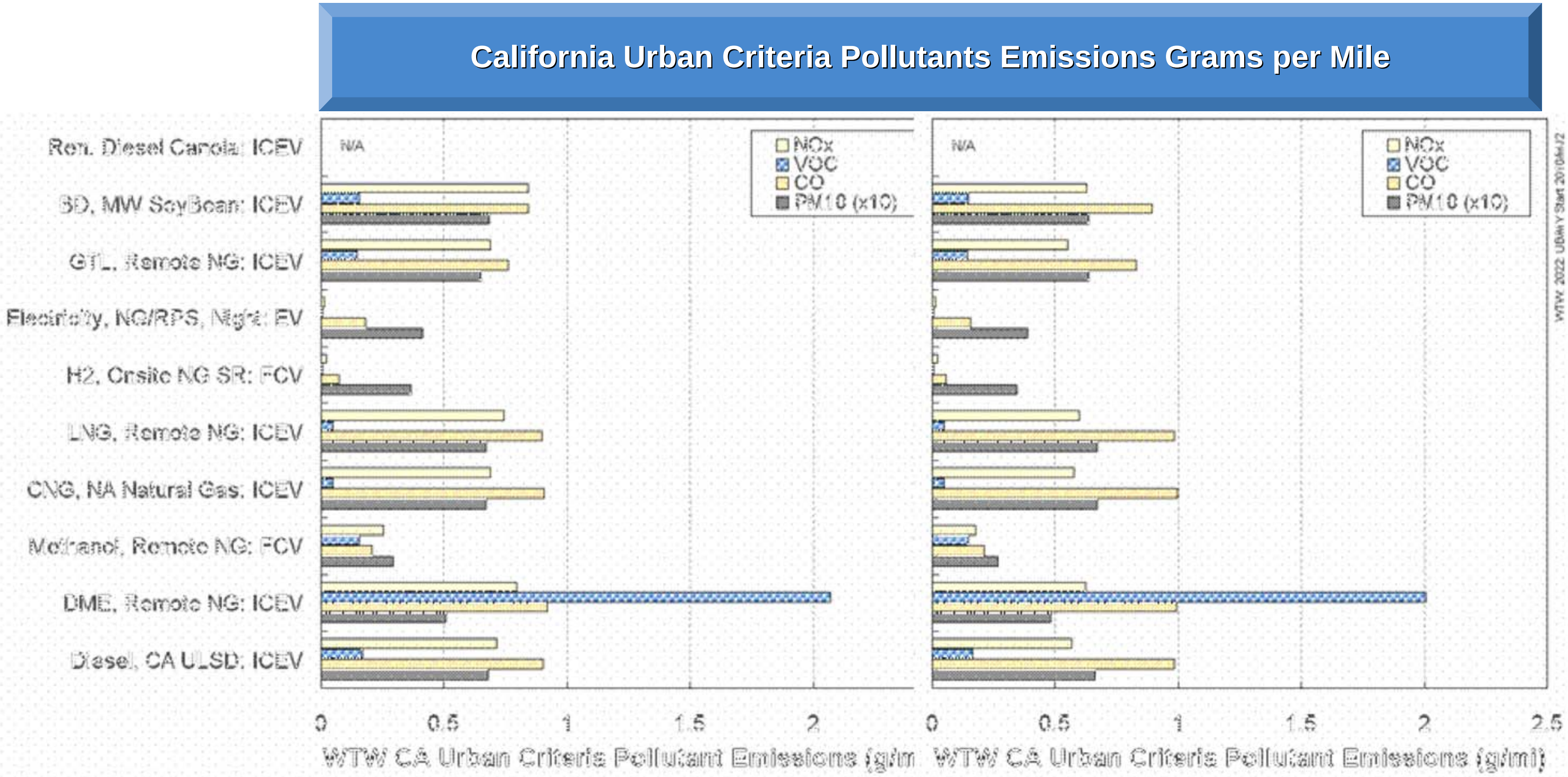
Greenhouse Gas Emissions
Grams of CO_2 Equivalent per Mile



Urban Buses in 2012
MY 2010+

Urban Buses in 2022
MY 2010+

"Well-to-Wheels" Criteria Pollutant Emissions Urban Buses



Midsize Cars in 2012
MY 2010+

Midsize Cars in 2022
MY 2010+

"Well to Wheels" Observations Urban Buses

- Zero emission technologies provide largest GHG benefit depending on fuel and fuel pathway
- CNG provides GHG benefits comparable to hydrogen (local stream reforming) and methanol (remote natural gas)

Fuel	GHG Benefit	Fuel	GHG Benefit	Fuel	GHG Benefit
CNG	22 to 24%	Battery EV	50 to 60%	Ren. Diesel Canola	20%
LNG	12%	Hydrogen FCV	25 to 30%	Biodiesel, MW Soybeans	12%
DME	0 to (4%)	Methanol FCV	17 to 19%	GTL, Remote NG	(4) to (5)%

- Criteria pollutants comparable to diesel for all alternatives
  - Hydrogen and electricity the lowest
  - High VOC for DME but like LPG could be controlled
- Toxic emissions dominated by diesel PM

1 Introduction

2 Methodology

3 Example Results—2010 Only

4 **Summary**

Alternative Fuels Provide Significant GHG Benefits in Midsize Autos but moderate or no Benefit in Urban Buses

- Depending on fuel pathway alternative fuels like ethanol, natural gas, LPG, electricity and hydrogen can provide significant reductions in well to wheels GHG emissions when used in midsize autos
  - Biofuels provide the large reductions (up to 80% compared to gasoline) depending on processing intensity since CO_2 emissions are recycled through plant photosynthesis
  - Low carbon containing fuels like natural gas and LPG also reduce GHG emissions (up to 27% compared to gasoline)
  - Zero carbon fuels/power also substantially reduced GHG emissions depending on fuel or power production technologies and pathways
    - Hydrogen produced from natural gas using steam reforming provides 40 to 50% reduction
    - Electricity in PHEV reduces GHG by up to 48%
    - Battery EVs can reduce GHGs by up to 85% depending on pathway
- Similar reductions for urban buses with 23% reduction for CNG and 60% reduction for battery electric buses. DME and GTL slightly increases GHG emissions

Most pathways result in comparable emissions of criteria and toxic emissions for both midsize autos and urban buses

- For midsize autos alternative fuel pathways result in criteria emissions comparable to gasoline
  - LPG VOCs higher if refueling not controlled
  - Local biomass conversion (California cellulosic ethanol) increases PM and NOx emissions, but these decrease over time
  - Natural gas based hydrogen and electric pathways reduce criteria pollutants
  - Toxics dominated by diesel exhaust PM
- For urban buses alternative fuel pathways also comparable to diesel
  - Hydrogen and electric drive have lower emissions than diesel
  - Toxics dominated by diesel PM emissions and options roughly comparable

What are the Major Conclusions of the Full Fuel Cycle Analyses?

- Improved efficiency lowers GHG, criteria, and toxic emissions
  - Production
  - Distribution
  - End-use
- Electricity provides lowest overall impact on GHG, criteria, toxic emissions and water pollution
- Biofuels very effective at recycling carbon and providing low GHG emissions, but harvesting, collection, production, and fuel distribution can affect GHG and local emissions
- Neat fuel use provides greatest per vehicle GHG benefits
- Alternative fuel blends with existing gasoline and diesel fuels can also be an effective strategy to reduce GHG emissions

Thank you for your Attention

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